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Operation
NOUGAT
SHOT HARD HAT

PROJECT OFFICERS REPORT—PROJECT 3.2

ELECTRONIC MEASUREMENTS IN ROCK AND TUNNEL LINER STRUCTURES (U)

L. M. Swift, Project Officer

Stanford Research Institute
Menlo Park, California

Issuance Date: July 19, 1963

others.
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ABSTRACT

On Project 3.2, measurements were made of transient particle velocity and displacement, relative displacement, and liner and rock strain, on 24 of the 43 tunnel liner sections used in the tunnel liner response studies (Project 3.1) on Shot Hard Hat. Of the 108 instrumentation channels installed, only about 45% of the gage channels produced useful records. Some of these records were partial, being terminated by cable breakage before completion.

The records obtained show peak values satisfactorily close to the set ranges; no records were lost due to over-ranging or under-ranging.

No detailed interpretation of these data has been attempted on this project; they will be used primarily in conjunction with other data obtained by Project 3.1. One general conclusion drawn from these data is that the majority of the structures showed maximum loading nearer the transverse than the radial direction.

PREFACE

Project 3.2 is pleased to acknowledge the assistance of Mr. Robert Holmes, Holmes and Narver, Inc., in implementing this project.

The field party for Project 3.2 was under the general supervision of L. M. Swift, assisted by W. M. Wells and L. H. Inman. Field party members included H. E. Aumiller, G. S. Brink, J. R. Fort, L. C. Harlen, H. H. Kaufman, A. L. Lange, D. C. MacLachlan, R. V. Ohler, G. Wagner, and C. M. Westbrook.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The objectives of this project were to make measurements of the input to and response of tunnel liners under conditions of explosive loading produced by Shot Hard Hat (depth of burial 950 feet, predicted yield 5 kt) and to report the data obtained in a form useful to structural engineers and designers.

The measurements to be made were primarily those specified by Project 3.1 (Reference 1) technical representatives and their consultants. However, the Stanford Research Institute (SRI) recognized that a part of the SRI responsibility was to design and utilize the most effective techniques for obtaining the desired data, recommending modifications to the overall experiment whenever the results could be improved thereby.

1.2 BACKGROUND

The Department of Defense (DOD) has need of data on the input to and response of tunnel liners of various configurations, resulting from nearby nuclear explosions. These data are required for guidance in the design of protective construction for underground facilities as well as for design of shafts, tunnels, and associated facilities in underground nuclear tests. A limited experiment of this type was originally planned for Project Gnome. It was expanded and transferred to Project Lollipop early in the planning for that event.

Stanford Research Institute undertook a portion of Program 29 of Project Lollipop under contract with the Atomic Energy Commission. That project involved dynamic measurements essentially identical to those covered by this report. The purchase of most of the necessary capital equipment and supplies and the installation of the recording equipment at the site were nearly complete under that project. These facilities were transferred to Shot Hard Hat and the experiment was completed under DOD sponsorship.

CHAPTER 2

EXPERIMENT DESIGN

The overall program of Project 3.1 involved utilization of 43 test sections having a variety of liners, or no liner at all, originally to be located at three ranges (500, 350, and 250 ft) from the zero point (Reference 1). These three ranges were selected to give maximum probability of producing meaningful damage without complete destruction to the sections at one or more ranges. Under Project 3.2, a total of 108 electronic measurement channels were planned (Table 3.1 and Figure 3.5).

The following paragraphs describe the division between types of measurements to be made.

2.1 LINER DEFORMATION

Most of the liners were circular in cross-section (Figure 2.1). A single measurement of the change in the diameter along a radius to the shot point was expected to give satisfactory information on the distortion of the liners, since they were expected to deform primarily in a simple elliptical mode with the total circumferential length essentially unchanged. However, as a check on the validity of this expectation, deformation across two diameters was measured on some liners. Deformation measurements were made in 17 test sections, five of which were instrumented on two diameters.

2.2 LINER MOTION

The absolute motion of a liner may be more important than the deformation when damage to the contents of a structure is more important than damage to the structure itself. In this experiment, absolute motion measurements were made with the velocity gage developed at SRI (Reference 2). In general, one such measurement was expected to describe the motion adequately, especially when it was associated with a measure of deformation, but in a few cases it appeared desirable to measure the liner velocity at the point away from the charge as well as that closest thereto. Liner motion measurements were conducted on 18 of the liners,

with three of them instrumented in these two positions. These liners included 14 of those on which deformation measurements were made.

2.3 STRAIN IN LINERS

Measurement of circumferential strain in the liners was considered an important measure of incipient failure. These data were obtained by attaching SR-4 strain gages to the inner surface of a steel liner or to the rods of a reinforced concrete liner. Such measurements were made on 11 liners, with five of these liners instrumented in two positions separated by 90 degrees. In addition, one of the liners was instrumented with strain gages to measure longitudinal strain in the liner material in these same two positions.

2.4 RADIAL STRESS IN THE ISOLATION MATERIAL

Many of the test sections were separated from the formation by an annulus of plastic foam or cinders. Stress in these isolation materials under dynamic loading is an important measure of their usefulness. The unit load on the liner or on the wall gives a satisfactory measurement of this stress. On this project, a stress gage was mounted flush with the surface of the liner. Such measurements were made on 10 liners, eight of which were isolated by foam and two by cinders. Seven of these liners were instrumented at two positions 90 degrees apart. On one liner these measurements were supplemented by measurements of the change of total thickness of the isolation material under dynamic loading.

2.5 STRAIN IN THE SURROUNDING ROCK

The presence of the tunnel itself has an effect on the dynamic pattern of stress and strain in the surrounding medium. This effect is reduced when a very stiff tunnel liner is placed in intimate contact with the medium, but it is by no means eliminated unless the liner is extremely stiff. The strain was measured in the medium at two or three distances from the surface in two or three positions relative to each of three types of section: no liner, a very stiff liner, and an intermediate, that is, limber liner. A total of 38 channels were utilized in these measurements.

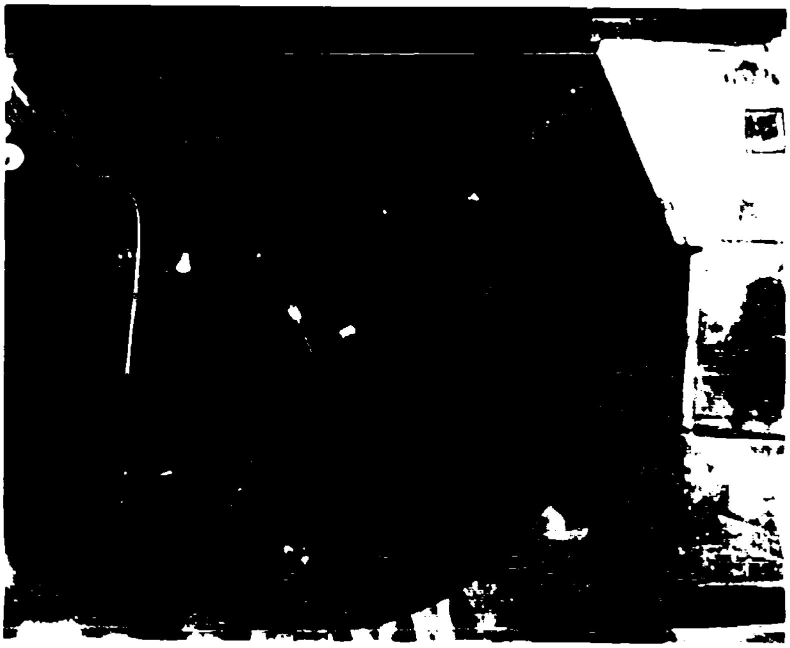


Figure 2.1 Typical tunnel liner, Shot Hard Hat. (DASA 032 (NOU-072-05) NTS-62)

CHAPTER 3

INSTRUMENTATION

3.1 TRANSDUCERS

All transducers were balanced variable-reluctance or variable-resistance half-bridges except some of the strain gage circuits which were full bridges. These instruments were selected to be compatible with the recording equipment used and whenever possible to be of types proven in similar field uses.

3.1.1 Relative Displacement Gages. The gages used for measurement of liner deformation and the deformation of isolation material were the Sandia-SRI relative displacement gages (Figure 3.1) used for similar purposes on a number of operations (Reference 3). In principle this gage consists of a spring-driven drum around which is wound a length of small piano wire, the far end of which is attached at the opposite side of the liner. The wire is kept in tension by the spring-driven drum, and any relative motion between the two anchor points is reflected in rotation of the drum which in turn rotates a potentiometer. The potentiometer is connected as a portion of the bridge in the recording system.

These gages were mounted and calibrated during the normal build-up period, but the operating wires were then disconnected to permit access to the liners for other operations. In the final button-up these wires were reconnected to the anchors after all other access requirements had been met.

3.1.2 Velocity Gages. The velocity gages used for measurement of the absolute motion of the liners were a modification of the standard SRI Mark II velocity gage (Reference 2) permitting their operation at a slight angle off the horizontal (Figure 3.2). They consist essentially of the standard Mark II periodic vertical velocity gage with a weaker supporting spring installed and adjusted to support the pendulum at the angle at which the gage was mounted (23° from the horizontal in Drift A and 17° in Drift B). The spring was adjusted to produce zero electrical

unbalance when mounted. No critical locking or unlocking signals were required, but a cocking circuit was used for final time constant determination (Section 3.3.2).

3.1.3 Strain in Liners. Conventional Baldwin SR-4 strain gages were used for all strain measurements. In reinforced concrete liners they were attached to reinforcing rods made accessible by wooden plugs placed in the concrete during construction. The usual techniques of grinding the rod and mounting the gages were used. On corrugated steel liners the gages were placed directly in contact with the liner at a point midway between a trough and a ridge in the corrugations to measure as nearly as possible the compressive strain without bending effects. This precaution was necessary, because it was not feasible to place strain gage elements on the outside of the liner as well as on the inside. On liners with wood or steel lagging and heavy supporting rings, the strain gages were placed on the web of the supporting ring (Figure 3.3).

3.1.4 Radial Stress Gages. The unit loading on the liner was measured by mounting a Carlson-Wiancko stress gage flush with the outer surface of the liner in a special mount welded or poured in the liner during construction (Figure 3.2). The construction procedures were such as to provide a smooth surface of foam or cinders covered with a light plastic film. A mounting ring was provided for the Carlson gage, which allowed the gage to be forced, by a series of screws, against the foam or cinders, providing a small amount of pre-stress to insure good contact. Every effort was made to avoid producing any discontinuities in the surface which would materially affect the distribution of the loading in the vicinity of the gage.

In this use of the Carlson gage the difference in compliance of the gage and the concrete liner was not considered important, since both were very stiff compared with the foam or cinders.

3.1.5 Strain Gages in the Medium The strain gages used in the measurement of the strain in the surrounding rock were incorporated in core assemblies prepared by the U.S. Bureau of Mines for this operation (Figure 3.4). This application followed the same construction and installation practices developed by the Bureau of Mines for a number of tests involving HE shots of various sizes (Reference 4). The SR-4 gages were

cemented on prepared surfaces of granite cores taken from the general vicinity of the tunnel. These cores were then inserted in drilled holes and cemented in place with a grout matching as nearly as possible the characteristics of the granite. Electrically, these gages were connected in the usual full-bridge circuit.

3.1.6 Summary. A summary of gage types and locations is presented in Table 3.1. The identification used for the liners is that used on Project 3.1. Figure 3.5 is a plan view of the test drift sections indicating the liner material and filler and the instrumentation orientation.

3.2 RECORDING EQUIPMENT

The basic recording system was essentially the same as that used on many previous operations (Reference 3). Consolidated Electrodynamics Corporation (CEC) 3-kc carrier amplifier systems were used on all resistance-wire strain gage circuits. The other gage channels utilized modified Wiancko oscillator-demodulator carrier systems. All channels were recorded on Miller or CEC direct-recording oscillographs, many of them in duplicate to avoid the possibility of loss of data from the failure of a single recording oscillograph. On some of the dual channels, galvanometers with different sensitivities were used to provide a wide dynamic range of usable sensitivities. Using a paper speed of about 40 in /sec, the standard oscillograph was limited to a recording time of slightly under 2 minutes. A timing signal of 100 and 1000 cps was applied to all records simultaneously from a single source, having a time accuracy of better than 10 parts per million. This gives the same time base to all records for time correlation of the separate events.

All instrument recording gear was located in a wooden shelter about 2000 feet southeast of surface zero (Figure 3.6). This location was chosen as a compromise between excessive cable length and the expected ground motion reaching the recording point. No protection from radiation was considered necessary.

The recording equipment was powered during set-up and test by 120-volt ac generators, but during the shot, storage batteries were used as the power source to gain maximum reliability. Multiple dc-to-ac converters were used to avoid gross failure from any single converter failure. All instruments were started in sequence from standard Edgerton, Germeshausen & Grier, Inc., (EG&G) timing signal

relays. Power was applied for warm-up at *H* minus 15 minutes backed up by an *H* minus 5-minute signal. Oscillographic recording started at *H* minus 15 seconds with a back-up contact at *H* minus 5 seconds.

3.3 CALIBRATION

All gages were calibrated on the channel and cable with which they were used on the shot itself. At the time of each calibration a synthetic calibrating signal, generated in the oscillator-amplifier system, was applied to the channel and the resultant galvanometer deflection was observed. This same signal was automatically applied approximately 5 seconds before zero time on the final run, so that the ratio of the two deflections could be accurately measured and used to compute any intentional or unintentional changes in system sensitivity subsequent to calibration. This system has been used by most of the agencies participating in blast effects measurements. Calibration procedures for the different types of gages differed in detail but not in principle.

<u>3.3.1 Relative Displacement Gages</u>. These gages are subject to direct calibration by simply moving the steel wire under tension a known distance and observing the galvanometer deflection. In practice, a screw mechanism was used to move the wire precise distances, and several points were observed ranging from a fraction of the set range to 1.5 or 2 times the set range in both positive and negative directions. A calibration curve was derived from these points.

<u>3.3.2 Velocity Gages</u>. When the SRI Mark II velocity gage is used in any other position than horizontal, the armature is brought to balance by a spring as shown in Figure 3.7. The effective pull of the spring is proportional to $g \sin \alpha$, where α is the angle of departure of the mounting axis from the horizontal. For calibration, the gage is cocked by the solenoid, then turned in the reverse vertical position so that the spring is down. The solenoid is then released, and the record is taken of the output of the gage as the armature moves through zero. The force acting on the armature as it passes through zero is proportional to 1 g plus the force of the spring. The calibration, then, is such that the distance y which the spot moves in t seconds corresponds to a velocity of $gt(1 + \sin \alpha)$, so that the velocity per unit deflection is

$$S = V/D = gt(1 + \sin \alpha)/y$$

In these gages the viscous restraint of the armature is produced by a silicone oil of high viscosity. The oil viscosity does not change with temperature as much as do other oils, but the change is still of the order of 1%/°F. This materially affects the calibration, since the temperature at calibration may be quite different from that after installation. Correction for this temperature effect is made by measuring the time constant of the gage at the time of calibration, and again as late as possible after installation.

This measurement is made as follows:

Immediately after calibration, the gage is mounted in its operating position, and the armature is deflected by the magnetic cocking coil. A record is taken of the return of the spot to its zero position. This curve should be an exponential, of the general form $y = Ae^{-t/T}$. The time constant T is independent of the gain of the system or of the time chosen for the start of measuring t, and is proportional to the viscous restraint. After the gage has been installed and has come to thermal equilibrium, the procedure is repeated to obtain the final time constant T_0. The final sensitivity S_0 is equal to ST_0/T.

In this project two mounting angles were encountered: 23 degrees in Drift A and 17 degrees in Drift B. The gages were built, adjusted, and calibrated for these angles. The true angles at the time of use were slightly different from these values, but the re-adjustment of the springs to these slightly different angles did not change the basic calibration of the gage.

3.3.3 Strain Gages. The procedure used on the SR-4 strain gages was the indirect method which is necessarily used on all gages of this type. The gage factor of each gage is specified by the manufacturer. This factor is the proportionate change in resistance of the gage induced by change in its length (strain). This factor is usually approximately 2, meaning that a 1% change in length would produce a 2% change in resistance. Known values of high resistance are shunted across one of the gage elements for calibration. Such a shunt changes the resistance of the bridge element by a known amount in a direction corresponding to compressive strain; hence, its equivalent strain may be computed and the deflection produced thereby used as a calibration point. These shunts must be applied as near as possible to the gage elements to avoid

errors due to the resistance of the connecting wires. In this operation this was readily possible, except for some of the core-mounted gages where the shunts were necessarily applied about 10 feet from the gage. The error produced thereby is negligible.

3.3.4 Carlson-Wiancko Stress Gages. The stress gages were calibrated by placing the entire gage in the high-pressure tank built for this purpose which provides electrical connection to the gage from the outside. Several values of air pressure were applied to the tank and the calibration recorded in the standard fashion.

3.3.5 General Procedures. Each gage calibration was calculated in the field as a check on the validity of the calibrations and for use in the field data reduction.

After return to the laboratory, the data were reprocessed without regard to the field calculations.

3.4 PREDICTIONS

In an experiment of this type, predictions must be made of the magnitude expected at each gage of the various parameters being measured, so that the gage range and the sensitivity of the recording equipment may be selected appropriately. These predictions are made for this purpose only and not with any intent of developing general prediction criteria.

On this project, the gage ranges were set in accordance with predictions furnished by Project 3.1, as shown in Table 3.1. The predictions for strain in the rock and particle velocity were also derived independently as a part of Project 1.2 (Reference 5). These two sets of predictions were found to be essentially identical, so no changes were made to the 3.1 predictions.

TABLE 3.1 GAGE LAYOUT

(Gage code is defined at the end of the table) ppk = parts per thousand

Liner	Material	Filler	Range ft	Gage Code	Gage Type	Set Range
A3a	R/C Hvy	None	244	A3aVR	VH23°	70 ft/sec
A3a	R/C Hvy	None	244	A3aDR	SC Displ.	12 in.
A3b	R/C Hvy	Foam	244	A3bVR	VH23°	35 ft/sec
A3b	R/C Hvy	Foam	244	A3bDR	SC Displ.	12 in.
A3c	R/C Lt.	Foam*	244	A3cSC0-0	Core	4 ppk
				A3cSR0-1	Core	4 ppk
				A3cSC0-2	Core	4 ppk
				A3cVR	VH23°	35 ft/sec
				A3cDR	SC Displ.	12 in.
				A3cPR	Carlson	300 psi
				A3cPP	Carlson	300 psi
A3d	R/C Hvy	Cinders	244	A3dVR	VH23°	50 ft/sec
A3d	R/C Hvy	Cinders	244	A3dDR	SC Displ.	12 in.
A5a	No. 3 Steel	Foam*	244	A5aVR	VH23°	35 ft/sec
				A5aSC0-L	SR-4	5 ppk
				A5aSC90-L	SR-4	5 ppk
				A5aDR	SC Displ.	12 in.
				A5aDP	SC Displ.	12 in.
				A5aPR	Carlson	300 psi
				A5aPP	Carlson	300 psi
A5b	No. 3 Steel	Foam	244	A5bVR	VH23°	35 ft/sec
				A5bSC0-L	SR-4	5 ppk
				A5bDR	SC Displ.	12 in.
				A5dDP	SC Displ.	12 in.
A5c	No. 3 Steel	Cinders	244	A5cVR	VH23°	50 ft/sec
A5c	No. 3 Steel	Cinders	244	A5cDR	SC Displ.	12 in.
B1a	Unlined	None	334	B1aSC0-0	Core	2 ppk
				B1aSC0-1		
				B1aSR0-1		
				B1aSC0-2		
				B1aSR0-2		
				B1aSC45-0		
				B1aSC90-0		
				B1aSR90-1		
				B1aSC90-2		
				B1aSC180-0		
B2a	Unlined	None	334	B2aSC0-0	Core	2 ppk
				B2aSC0-1		
				B2aSR0-1		
				B2aSC0-2		
				B2aSR0-2		
				B2aSC90-0		
				B2aSR90-1		
				B2aSC90-2		
				B2aSC180-0		
B3a	R/C Hvy	None	334	B3aVR	VH17°	35 ft/sec
B3a	R/C Hvy	None	334	B3aSC0-L	SR-4	2 ppk
B3a	R/C Hvy	None	334	B3aDR	SC Displ.	4 in.
B3b	R/C Hvy	Foam	334	B3bVR	VH17°	18 ft/sec
B3b	R/C Hvy	Foam	334	B3bSC0-L	SR-4	2 ppk
B3b	R/C Hvy	Foam	334	B3bDR	SC Displ.	4 in.
B3c	R/C Lt.	Foam*	334	B3cSC0-0	Core	2 ppk
				B3cSC0-1		
				B3cSR0-1		
				B3cSC0-2		
				B3cSC90-0		
				B3cSC90-2		
				B3cVR	VH17°	18 ft/sec
				B3cSC0-L	SR-4	2 ppk
				B3cSC90-L	SR-4	2 ppk
				B3cDR	SC Displ.	4 in.
				B3cPR	Carlson	150 psi
				B3cPP	Carlson	150 psi

TABLE 3.1 - Continued

Liner	Material	Filler	Range ft	Gage Code	Gage Type	Set Range
B3d	R/C	Cinders	334	B3dVR	VH17°	27 ft/sec
				B3dSCO-L	SR-4	2 ppk
				B3dDR	SC Displ.	4 in.
				B3dPR	Carlson	150 psi
B4a	WF Steel	Cinders	334	B4aSCO-L	SR-4	2 ppk
B4a	Steel Lag	Cinders	334	B4aSC90-L	SR-4	2 ppk
B4b	WF Steel Steel Lag	Foam	334	B4bSCO-L	SR-4	2 ppk
				B4bSC90-L		2 ppk
				B4bSLO-L		3 ppk
				B4bSL90-L		3 ppk
				B4bDR	SC Displ.	4 in.
				B4bDP	SC Displ.	4 in.
				B4bPR	Carlson	150 psi
				B4bPP	Carlson	150 psi
B4c	Wood Lag	Foam	334	B4cSCO-L	SR-4	2 ppk
B5a	No. 3 Steel	Foam°	334	B5aVR	VH17°	18 ft/sec
				B5aVR180	VH17°	18 ft/sec
				B5aSCO-L	SR-4	2 ppk
				B5aSC90-L	SR-4	2 ppk
				B5aDR	SC Displ.	4 in.
				B5aDP	SC Displ.	4 in.
				B5aPR	Carlson	150 psi
				B5aPP	Carlson	150 psi
				B5aFR	SC Displ.	3 in.
				B5aFP	SC Displ.	3 in.
B5b	No. 3 Steel	Foam	334	B5bVR	VH17°	18 ft/sec
				B5bVR180	VH17°	18 ft/sec
				B5bSCO-L	SR-4	2 ppk
				B5bDR	SC Displ.	4 in.
				B5bDP	SC Displ.	4 in.
				B5bPR	Carlson	150 psi
B5c	No. 3 Steel	Cinders	334	B5cVR	VH17°	27 ft/sec
				B5cVR180	VH17°	27 ft/sec
				B5cDR	SC Displ.	4 in.
				B5cPR	Carlson	150 psi
B6a	No. 5 Steel	Foam°	334	B6aVR	VH17°	18 ft/sec
B6b	No. 5 Steel	Foam	334	B6bVR	VH17°	18 ft/sec
B6b	No. 5 Steel	Foam	334	B6bPR	Carlson	150 psi
B6b	No. 5 Steel	Foam	334	B6bPP	Carlson	150 psi
B6c	No. 5 Steel	Cinders	334	B6cVR	VH17°	27 ft/sec
B7a	Horseshoe	None	334	B7aDR	SC Displ.	6 in.
C3c	R/C Lt.	Foam°	457	C3cDR	SC Displ.	1 in.
C3c	R/C Lt.	Foam	457	C3cPR	Carlson	120 psi
C3c	R/C Lt.	Foam	457	C3cPP	Carlson	120 psi

Typical gage codes are:

1	2	3	4	5	
C3c	S	C	0	-2	C3cSCO-2
A3a	D	R			A3aDR
B5a	V	R			B5aVR
B6b	P	P			B6bPP
B3a	S	C	90	-L	B3aSC90-L

The first group identifies the liner on which the measurement is made.

The second letter defines the type of measurement; S for strain, V for velocity, D for diameter change of lining, P for pressure on lining, and F for compression of foam.

The third letter describes the orientation of the gage; there is a certain inconsistency here; for strain gages, C is a measurement of circumferential strain, R radial strain and L longitudinal strain with respect to the tunnel. For other gages, R refers to a measurement radial with respect to the shot, and P to an orientation perpendicular to this radius, both types being radial to the tunnel.

The fourth number refers to the location of a gage when not otherwise obvious, in degrees from the zero point (which is the point closest to the shot). When there is no fourth number, 0 is understood.

The fifth number or letter explains the radial location of a strain gage; if a number, it refers to the number of tunnel radii it is deep from the tunnel surface, and an L indicates that it is located on the liner itself.

Foam = nominally 9 inches; Foam° = 24 inches.

The figure for range is the slant distance from shot point to the gage.

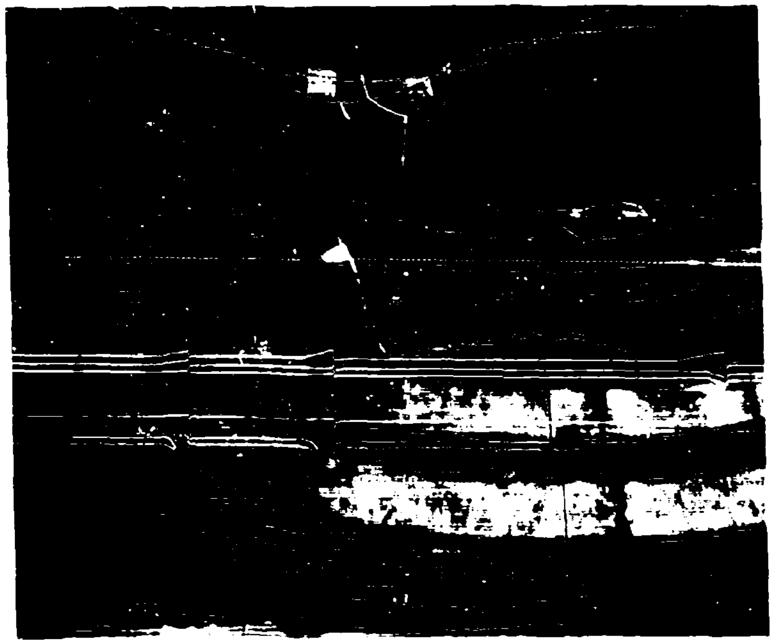


Figure 3.1 Relative displacement gage installed on Liner A5b. (DASA 047 (NOU-084-05) NTS-62)

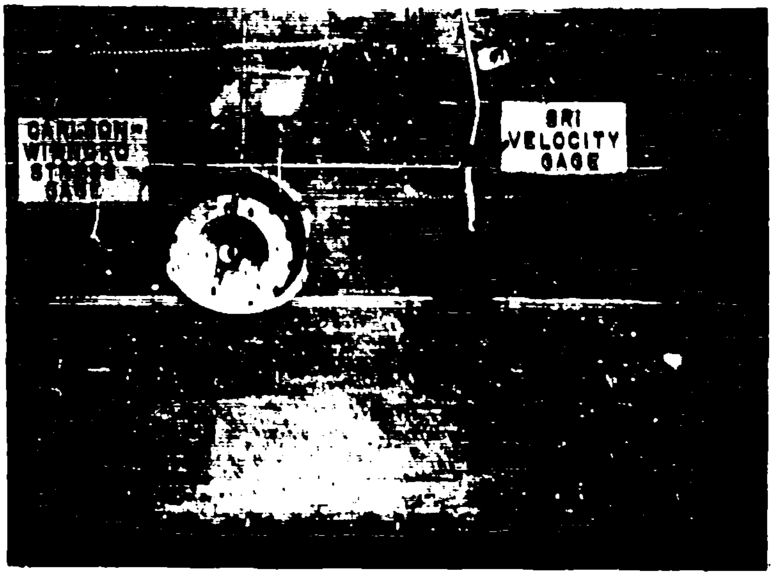


Figure 3.2 Foam pressure gage and velocity gage on Liner B3c. (DASA 032 (NOU-072-08) NTS-62)

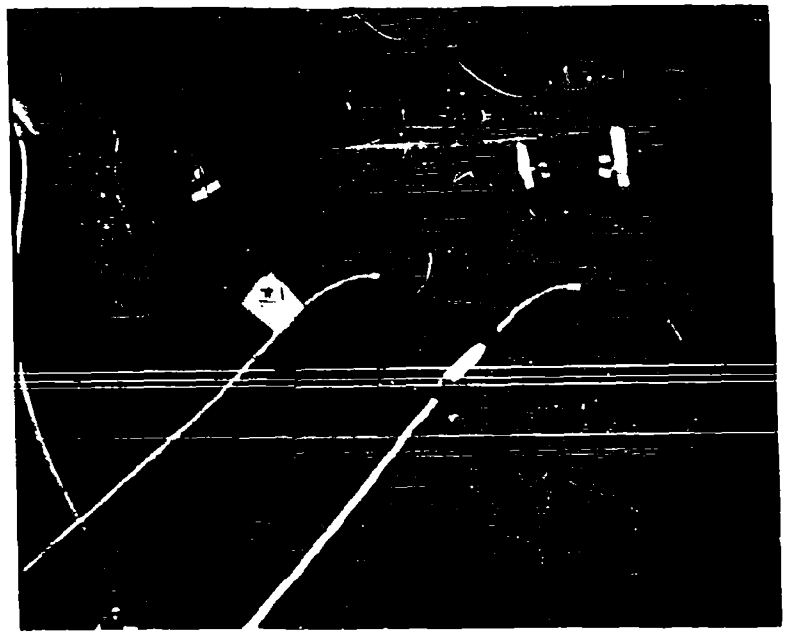


Figure 3.3 Baldwin SR-4 strain gages installed on liner. (DASA 047 (NOU-084-04) NTS-62)

Figure 3.4 Core strain gage before installation in formation. (DASA 056 (NOU-088-05) NTS-62)

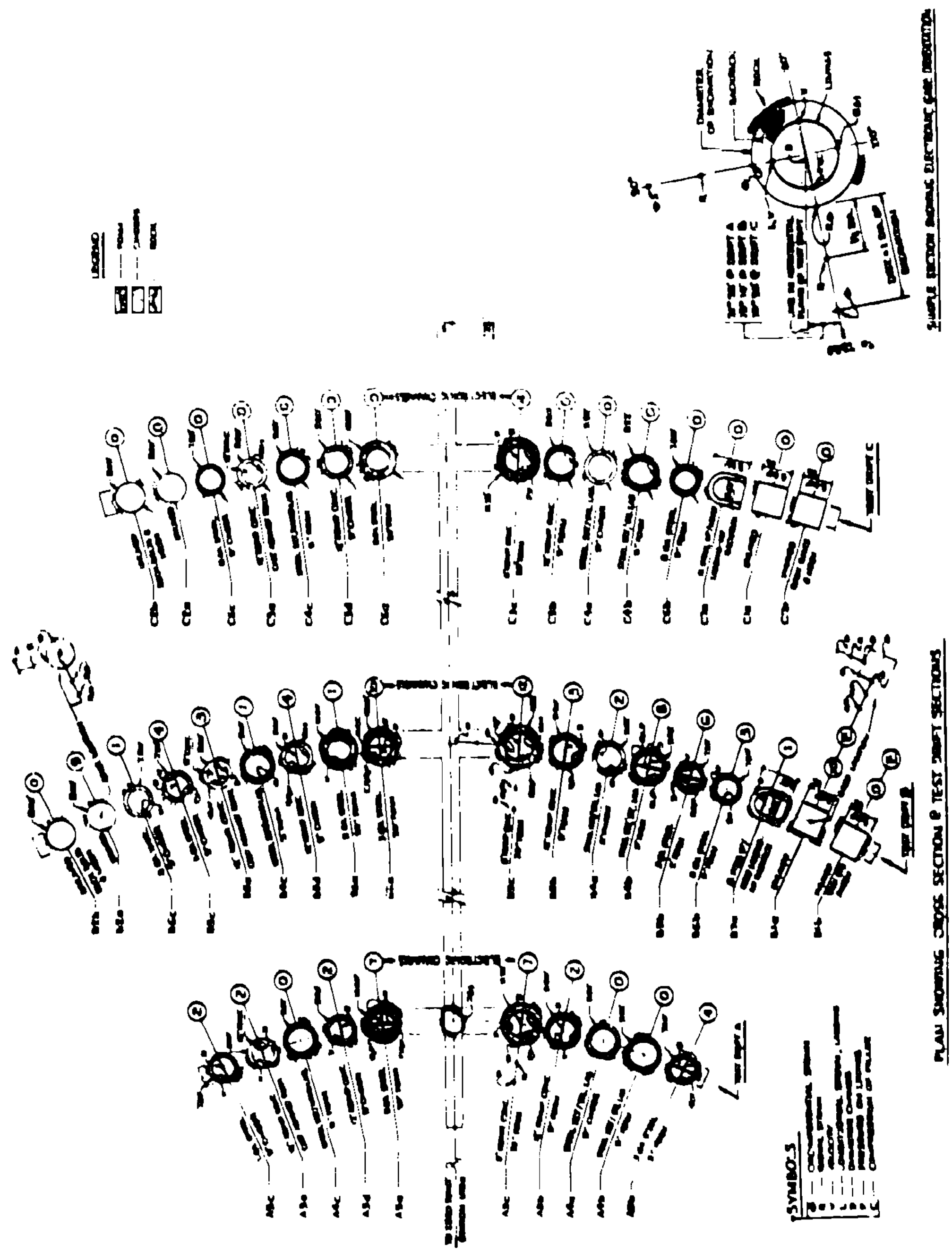


Figure 3.5 Structural response program instrumentation.

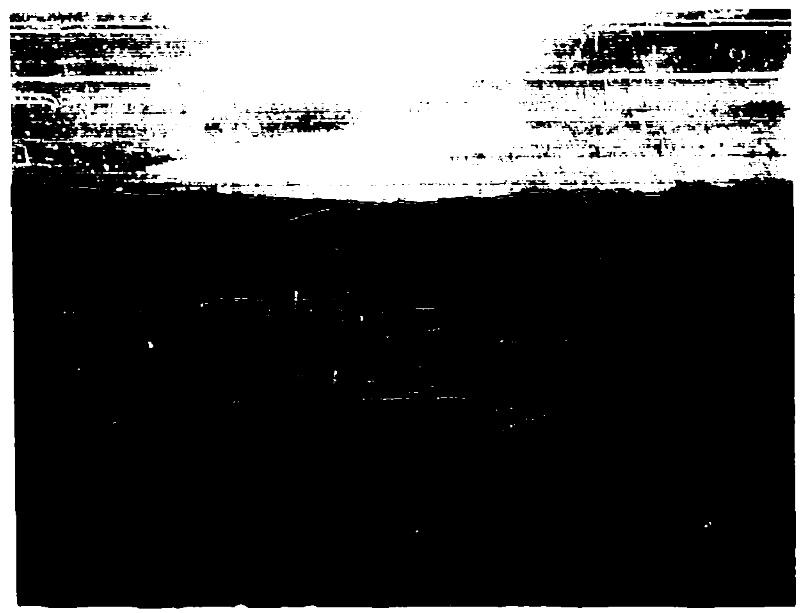


Figure 3.6 Recording area. (DASA 025 (NOU-069-07) NTS-62)

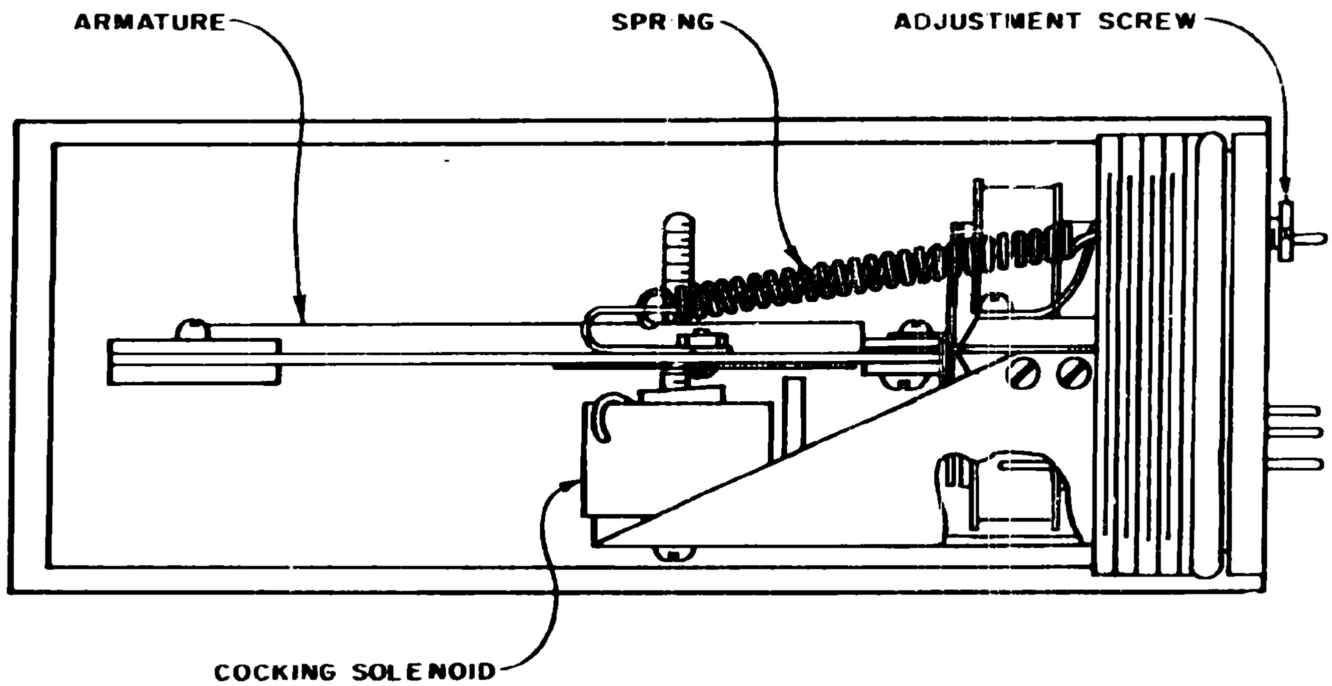


Figure 3.7 Sketch of SRI Mark II velocity gage.

CHAPTER 4

OPERATIONS

4.1 CHANGES IN EXPERIMENT PLAN

No changes in the basic experiment plan or location of gages were made after this project was in the early planning stages. Constructional difficulties, however, required some small changes in the ranges and angles of three drifts from the shot point. These revised dimensions are shown in Fig. 4.1, which also shows the vertical section of the entire experiment.

4.2 FIELD SCHEDULE

Part of the necessary installations for this project were conducted in the fall of 1960, for the planned event Lollipop. The central station equipment was installed in the shelter, and nearly half of the cables were run down the vertical shaft but not distributed to the tunnel drifts. After Lollipop was indefinitely postponed, these facilities were maintained as well as possible, including several trips to charge batteries, and so forth. It is not entirely clear whether these preparations were useful to the completion of the installation for Hard Hat, because part of the instruments were removed from the shelter for use on Shot Antler and a number of the cables were damaged by rodents; as a result, the necessary checks and repairs were time consuming.

Operations on Hard Hat began on December 1, 1961, with a small crew preparing and completing the cable lines and running the remaining cables down the vertical shaft. Full-scale field operations began on January 3, 1962, and continued until the shot date. Considerable delays were occasioned by continued construction activities in the tunnel, notably the installation of the blast door near the vertical shaft (Figures 4.2 and 4.3). However, gage calibration, connection, and installation were essentially complete by D-6 when button-up operations were started in the tunnel.

The recording shelter instruments were checked out and buttoned up by about 2230 on D - 1. Records were recovered on the afternoon of D-day and were developed during the day of D + 1. Central station equipment was recovered on D + 2, and the field party left the site on D + 3.

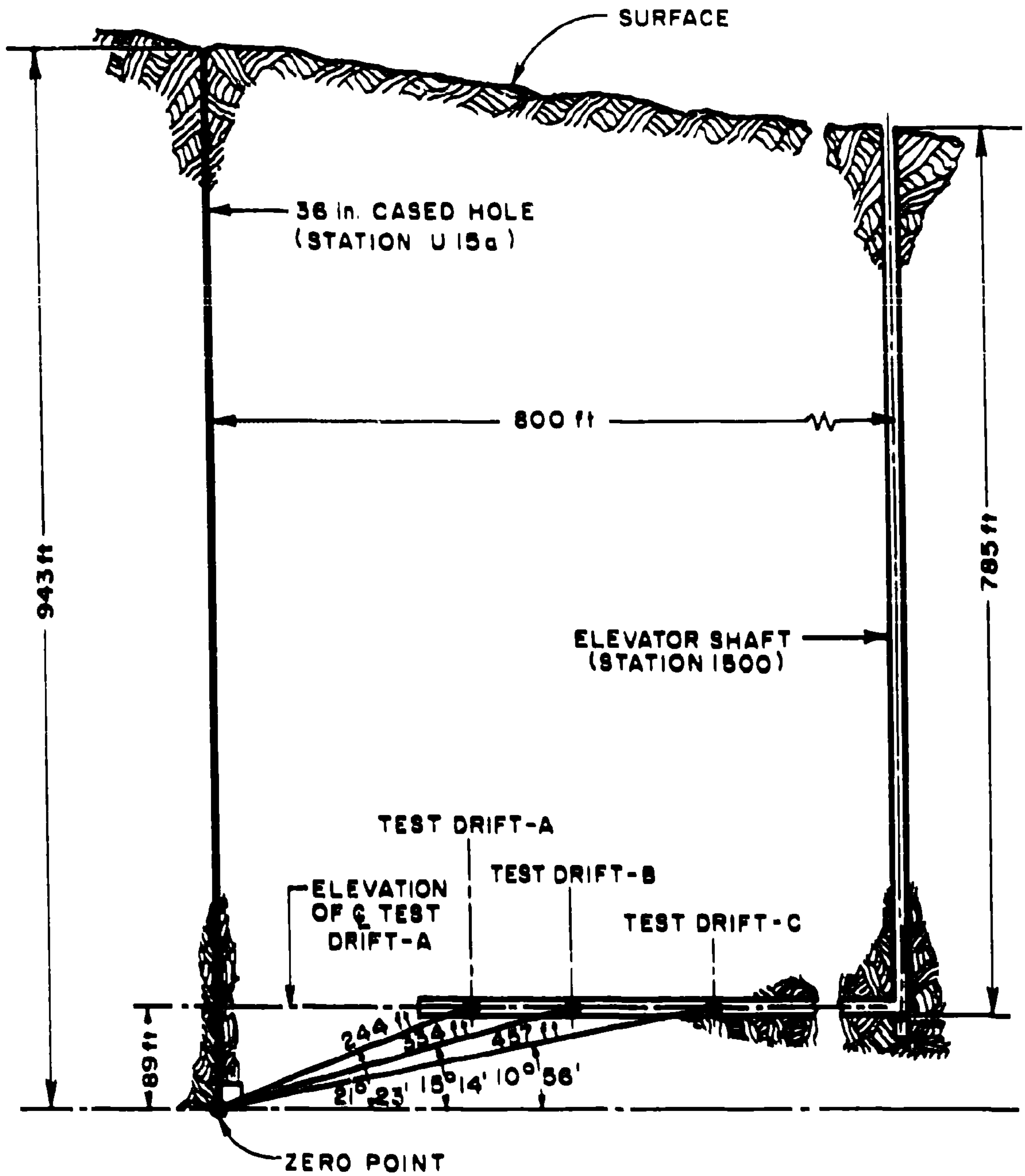


Figure 4.1 Vertical section showing locations of test drifts.

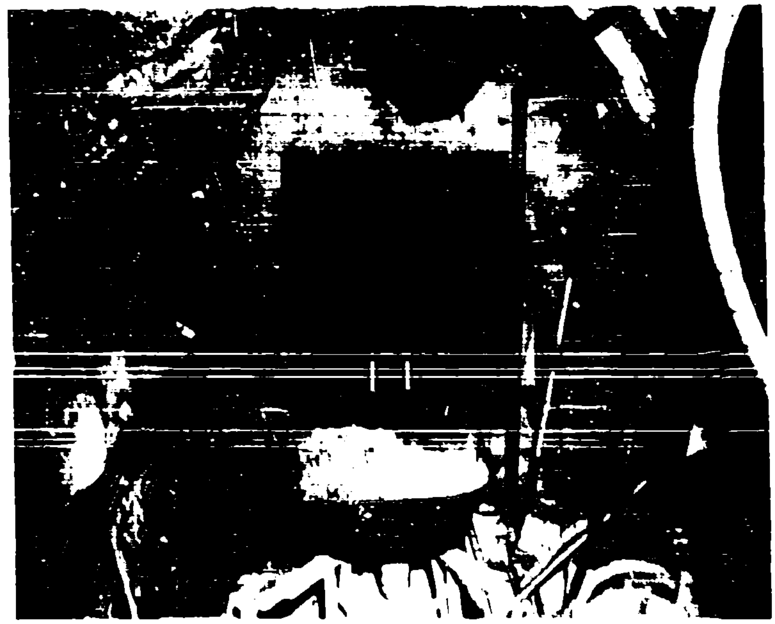


Figure 4.2 Blast door installation near vertical shaft. (DASA NOU-048 (NOU-086-04) NTS 62)

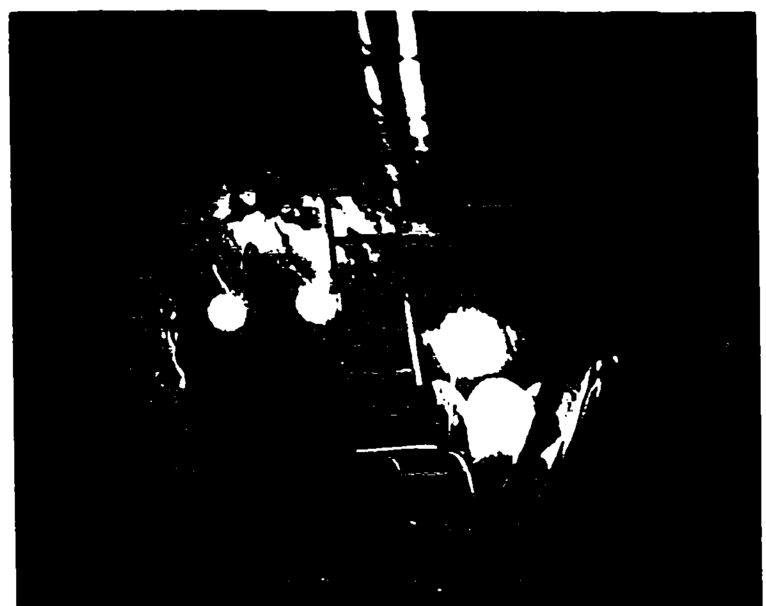


Figure 4.3 Typical working environment in tunnel. (DASA NOU-069-10-NTS-62)

CHAPTER 5

RESULTS

5.1 GAGE PERFORMANCE

Of the 108 gage channels installed, usable results were obtained from only 48 channels, representing 45% of the total. This high loss of channels appears to have resulted from a number of separate causes, as follows:

(a) Of the 10 recording oscillographs used on this project and on Project 1.9 (Reference 5), one recorder failed to transport paper thereby losing its gage records completely. Two others produced partial records due to failure of the circuits designed to increase the light brilliance on recording. This failure appears to have been caused by dusty or defective relays, since the recorders operated normally on final checkout.

(b) The transient electromagnetic disturbance at zero time, sometimes referred to as the induction signal, was much stronger on this than on any other underground shot we have instrumented. In some channels it was severe enough to preclude recording, and in others it caused a baseline shift which reduced the accuracy of the records.

The induction signal probably contributed to the loss of data from the resistance wire strain gages by flashover of the gage wire to the grounded liner or other material. In some cases, it cannot be determined whether this or cable breakage was the cause of failure.

In addition to the record losses mentioned above, deleterious effects of the ground motion were experienced on cables and recording equipment. Indications are that all of the cables suffered breakage at some time subsequent to zero time. A very few of these lasted as long as 300 milliseconds. Most broke at 30 to 100 milliseconds. On several of the channels which were otherwise acceptable, cable breakage may have occurred before the true peak was reached, resulting in quoted peaks which are probably less than the true value. The ground motion experienced at the recording shelter was considerably higher than expected and was sufficiently strong to damage some of the recording oscillographs and some of the electronic equipment. As a result, the tail end of a few of the records was lost, but most of the cables had already been broken before these failures.

This massive amount of lost data is much more severe than we had experienced on any other shot. Some of the losses were unavoidable, but some might have been avoided had they been anticipated. In particular, the severe damage from the induction signal was totally unexpected at the time that this experiment was planned, since it had not presented an important problem on previous underground shots; on the other hand, some cable damage was anticipated, considering the nature of the formation and the proximity to the source, but even this was more severe than had been anticipated. The recorder failures were at least partly due to the age and obsolescence of the recorders used, and modifications are presently in progress to replace or backup the photographic recorders with multichannel magnetic tape systems.

5.2 DATA PRESENTATION

Table 5.1 presents the values of pressure, velocity, displacement, and strain recorded on this project, with the times of peaks and total duration of the effective record. On channels where such a determination is reasonably certain, a first arrival time is also shown.

The polarity conventions used in Table 5.1 and all other data presentations herein are based on the expected direction of the predicted major motion, as follows:

(a) Particle velocity, -VR, -VR 180. Positive is away from the shot.

(b) Particle displacement, -VR-D, VR 180-D. Positive is away from the shot.

(c) Liner relative displacement, -DR. Positive is reduction of diameter. Liner relative displacement, -DP. Positive is increase of diameter.

(d) Foam thickness change, -FR, -FP. Positive is reduction of thickness.

(e) Strain, S. Positive is tension (elongation of gage).

Figures 5.1 through 5.4 show normalized and linearized plots of the majority of the records tabulated in Table 5.1, along with the pertinent peak data. These presentations utilize the same notation used in Table 3.1 for identification of the gages, with one addition; when the velocity records have been integrated to obtain displacement, the code used is the same as the original velocity gage with the addition of a -D.

Many of these curves have been edited to remove extraneous noise where this could be readily identified. Some of this noise may remain. Many of the records such as A3bVR, B3aVR, and A3aDR show one or more sharp spikes which may or may not be spurious. In editing the records it was thought best to err on the side of conservatism and to leave in those which were in doubt. However, even if real, the spikes are believed to be of little importance, and care is required in application of the peak data.

Most of the records purporting to show the stress in the foam surrounding the liner show negative pressures larger than seems possible. True, in the installations of these gages, a slight initial compressive force was applied between the Carlson gages and the foam (see Section 3.1.4), but this force was a small fraction of the range of the gage. These negative pressures are largely in the form of short spikes which may be spurious electrical disturbances, but the long duration of the negative pressure on G3cPR remains unexplained.

TABLE 5.1 DATA SUMMARY

Particle Velocity

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	ft/sec	sec	ft/sec	sec	sec	%
A3b	-VR	244	0.015	32.8	0.0245	21.4	0.023	0.031	94
A3d	-VR		0.0155	10.1	0.0195	18.5	0.0295	0.030	-37
A4a	-VR		0.015	104	0.0183	29.7	0.0220	0.025	300
B3a	-VR	334	0.019	130	0.039			0.060	370
B3b	-VR		0.020	22.7	0.030	9.4	0.100	0.100	126
B3c	-VR		0.020	20.2	0.040			0.109	112
B3d	-VR		0.022	31.0	0.255	31.0	0.066	0.073	115
B5a	-VR180		0.021	40.0	0.0345	5.4	0.0265	0.063	227
B5b	-VR		0.020	41.0	0.0325	32.0	[illegible]	0.076	228
B5b	-VR180		0.022	33.3	0.029	9.6	0.033	0.120	185
B5c	-VR		0.022	11.2	0.024			0.030	41.5
B5c	VR180		0.0235	10.0	0.027	28.8	0.0295	0.070	37
B6a	-VR	334	0.021	24.3	0.025	11.9	0.0335	0.070	135
B6b	-VR		0.020	24.2	0.042	15.0	0.034	0.042	134
B6c	-VR		0.020	13.5	0.0285			0.030	50
C3c	-VR	457	0.028	22.7	0.042			0.373	252

Particle Displacement

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	in.	sec	in.	sec	sec	%
A3b	VR-D	244	See	0.460	0.0305	0.32	0.024	0.031	
A3d	VR-D		Velocity	0.630	0.025			0.030	
A5a	VR-D		Records	2.84	0.025			0.024	
B3a	VR-D	334		15.7	0.0415			0.060	
B3b	VR-D			6.67	0.0695			0.100	
B3c	VR-D			>9.2	0.108			0.108	
B3d	VR-D			3.56	0.039			0.074	
B5a	VR180-D			>4.86	0.063			0.063	
B5b	VR-D			8.66	0.053			0.070	
B5b	VR180-D			>21.2	0.120			0.120	
B5c	VR180-D			0.25	0.028	3.30	0.0405		
B5c	VR-D			>0.43	0.0315			0.0315	
B6a	VR-D			0.80	0.028	>0.80	0.069	0.069	
B6B	VR-D			0.55	0.027			0.042	
B6c	VR-D			>0.67	0.030			0.030	
C3c	VR-D	451		7.98	0.104			0.390	

Strain

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	in.	sec	in.	sec	sec	%
B2a	SR90-1	334	0.019	0.88	0.024			0.033	32
B3c	SCO-L		0.022	0.67	0.037	1.03	0.0255	0.049	-52
B3d	SCO-L		0.022	1.70	0.024	0.59	0.033	0.040	85

TABLE 5.1 - Continued

Relative Displacement

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	in.	sec	in.	sec	sec	%
A3a	DR	244	0.016	5.89	0.026	2.40	0.030?	0.140	49
A3b	DR		0.019	0.48	0.060	1.04	0.0245	0.090	8.7(-)
A3d	DR		0.016	2.80	0.029	3.89	0.027	0.048	32(-)
A5a	DR		0.017	1.09	0.023	>2.77	0.026	0.033	23(-)
A5a	DP		0.017	9.32	0.030	1.82	0.025	0.032	78
A5b	DR		0.017	1.64	0.025			0.046	14
A5b	DP		0.016	5.14	0.020			0.029	43
A5c	DR		0.015	14.4	0.018	2.45	0.025	0.035	120
B3a	DR	334	0.019	4.82	0.031			0.031	121
B3b	DR		0.020	3.90	0.052	2.21	0.077	0.100	97
B3c	DR		0.022	3.83	0.075	1.56	0.0735	0.115	96
B5a	DR		0.023	1.82	0.037	>3.7	0.052	0.062	45(90-)
B5a	DP		0.025	9.50	0.057	4.81	0.064	0.068	237
B5b	DR		0.020	4.59	0.035	1.33	0.049	0.075	115
B5c	DR		0.020	2.27	0.042	1.36	0.061	0.066	57
B7a	DR		0.023	3.81	0.029	1.44	0.061	0.079	65

Foam Stress

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	psi	sec	psi	sec	sec	%
A5a	PR	244	0.0160	601	0.0255	99.4	0.028	0.035	200
A5b	PP		0.0165	487	0.0200			0.025	162
B3c	PR	334	0.021	143	0.134			0.105	95
B3c	PP		0.020	565	0.033	50.9	0.022	0.300	376
B4b	PR		0.021	169	0.0275	28.7	0.039	0.042	113
B4b	PP		0.022	295	0.0540	71.6	0.0365	0.070	196
B5a	PR		0.022	677	0.0475	296	0.0875	0.092	451
B5a	PP		0.026	197	0.0260	130	0.0365	0.056	131
B5b	PR		0.019	209	0.0235	64.0	0.030	0.041	139
C3b	PR	457	0.030	49.3	0.043	29.0	0.080	0.090	41
C3c	PP		0.029	118	0.040			0.099	98

Foam Deflection

Liner	Gage Code	Range	Arrival Time	Positive Peak	Time of Peak	Negative Peak	Time of Peak	End of Record	Percent of Set Range
		ft	sec	in.	sec	in.	sec	sec	%
B5a	FR	334	0.022	2.62	0.051	1.01	0.633	0.110	87
B5a	FP	334	0.022	2.03	0.049	4.61	0.067	0.090	133

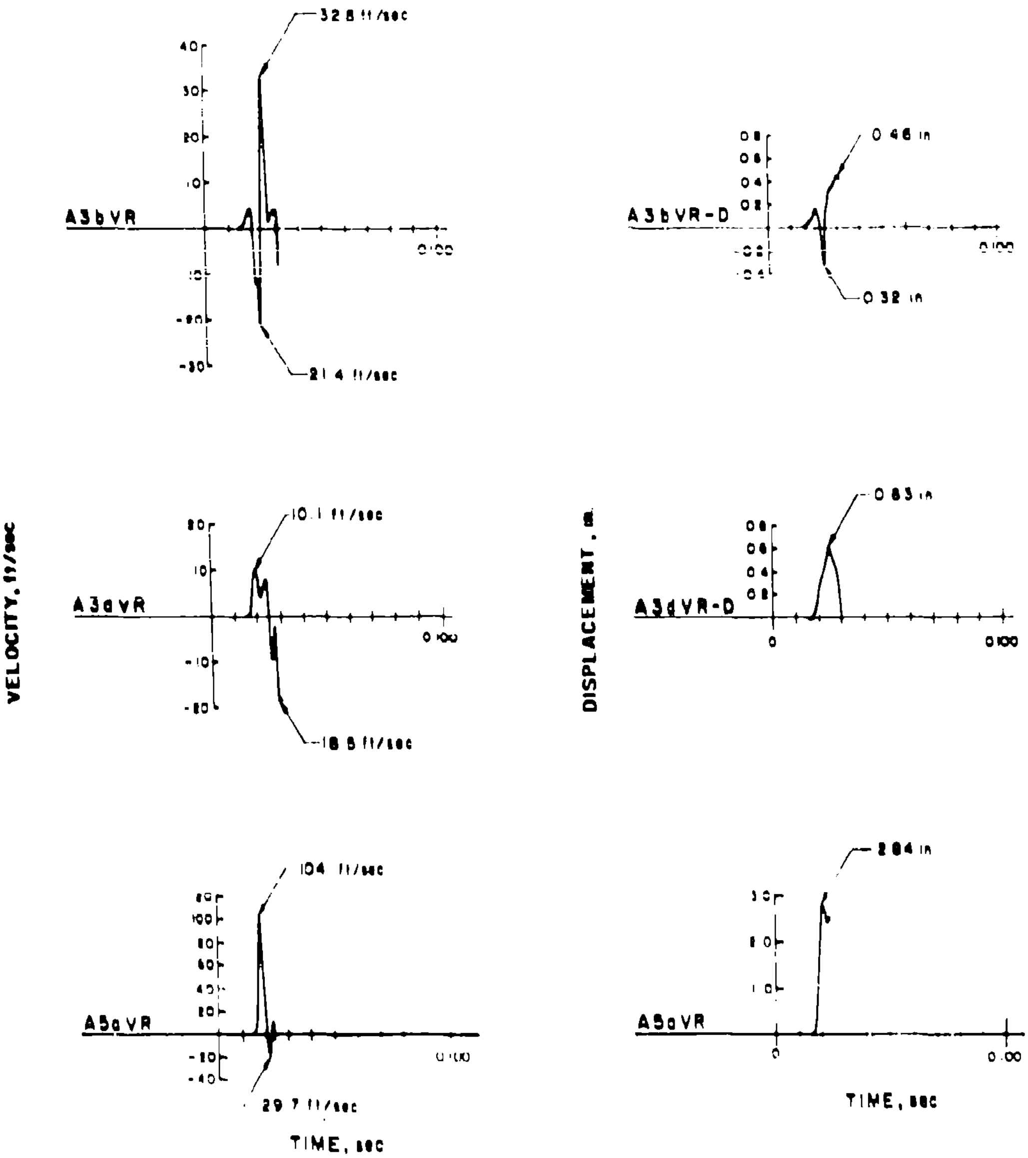


Figure 5.1 Measured particle velocities and derived particle displacements.

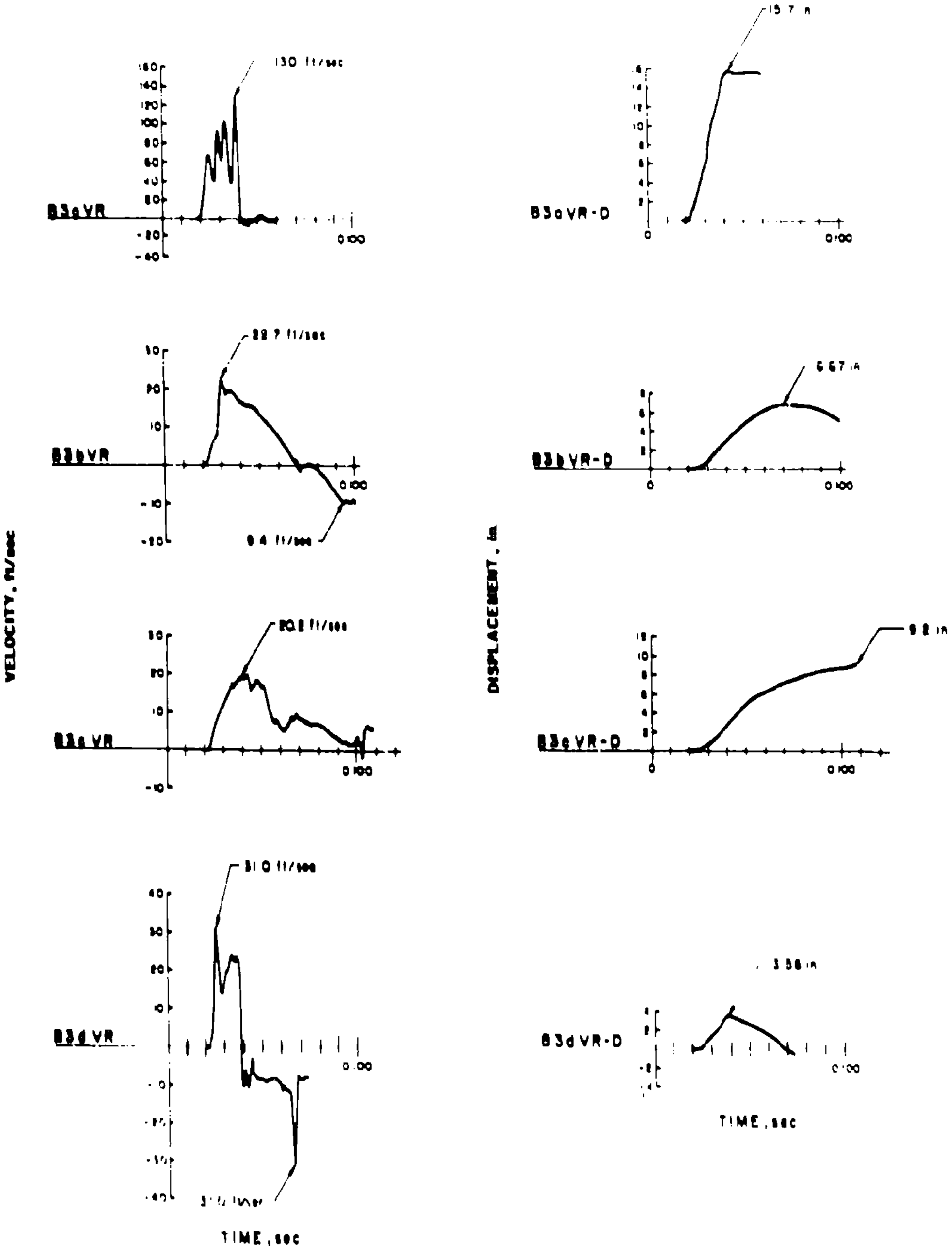


Figure 5.1 Continued.

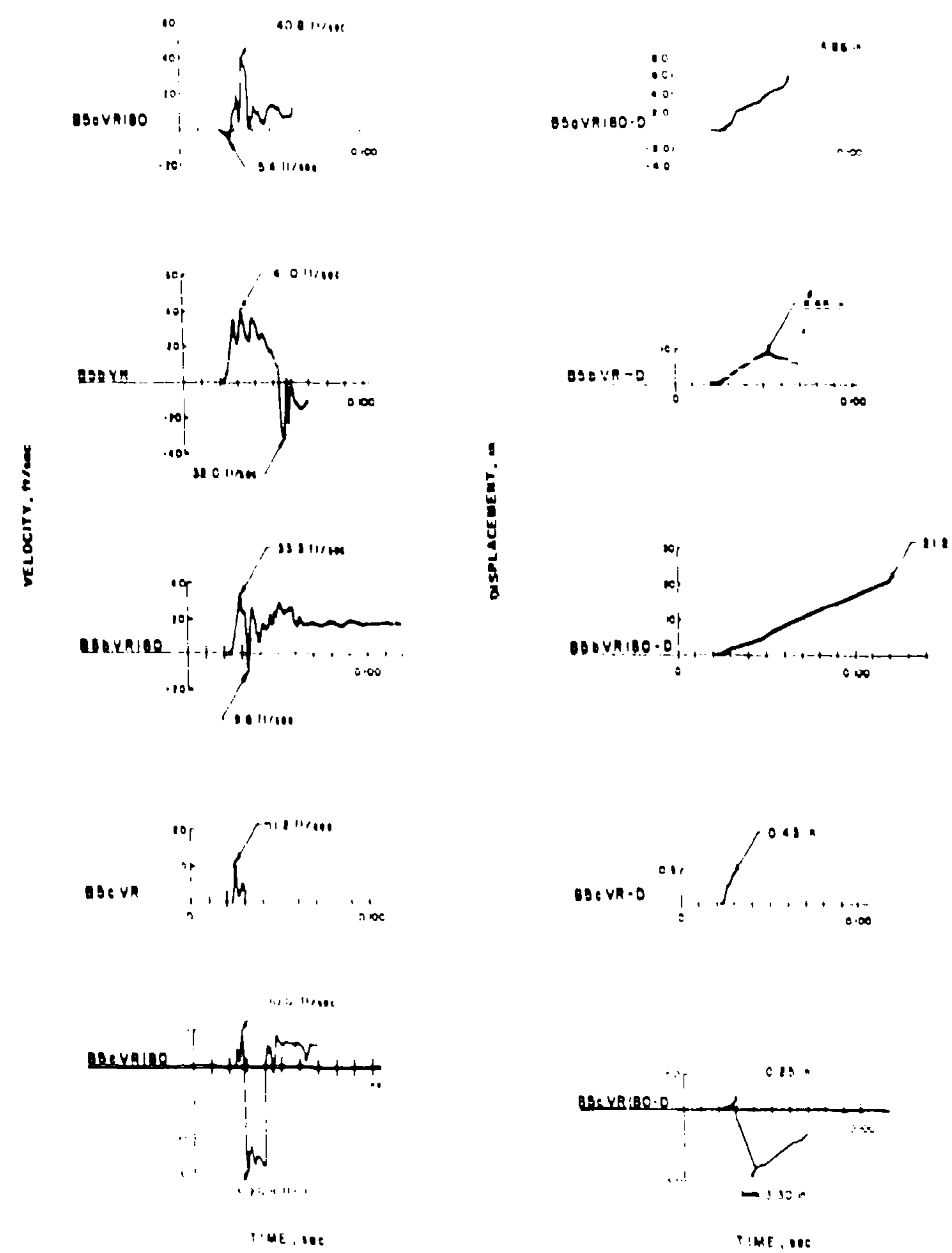


Figure 5.1 Continued.

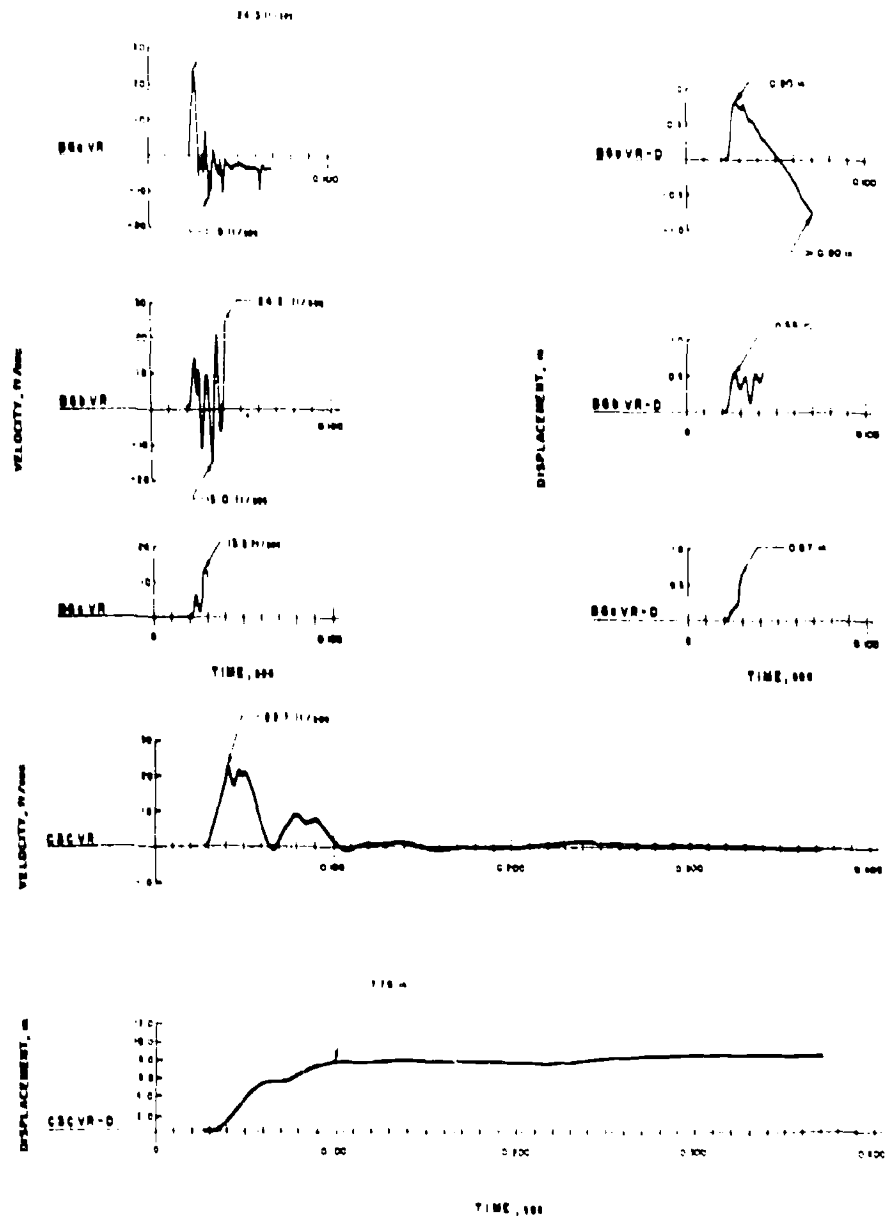


Figure 5.1 Continued.

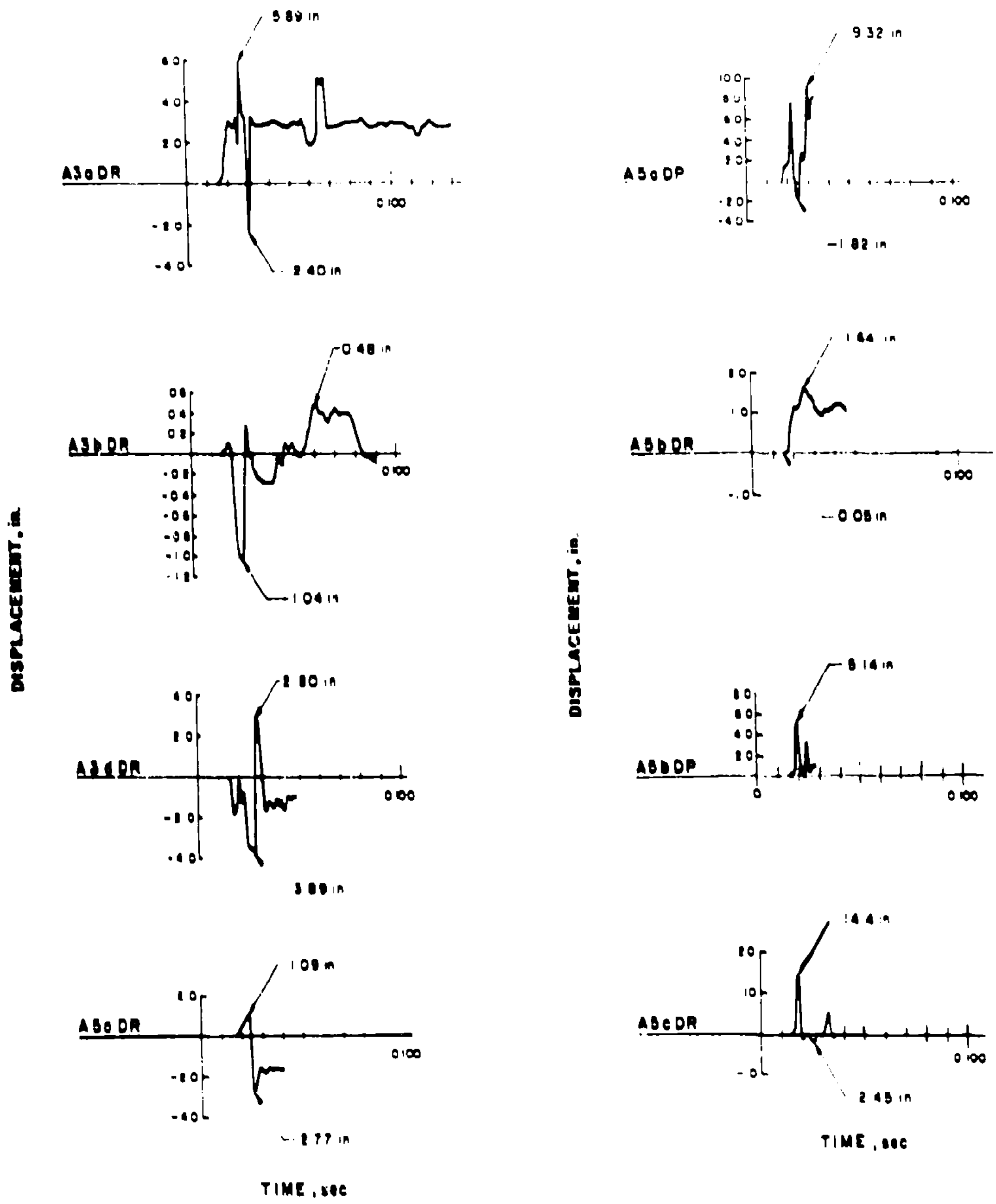
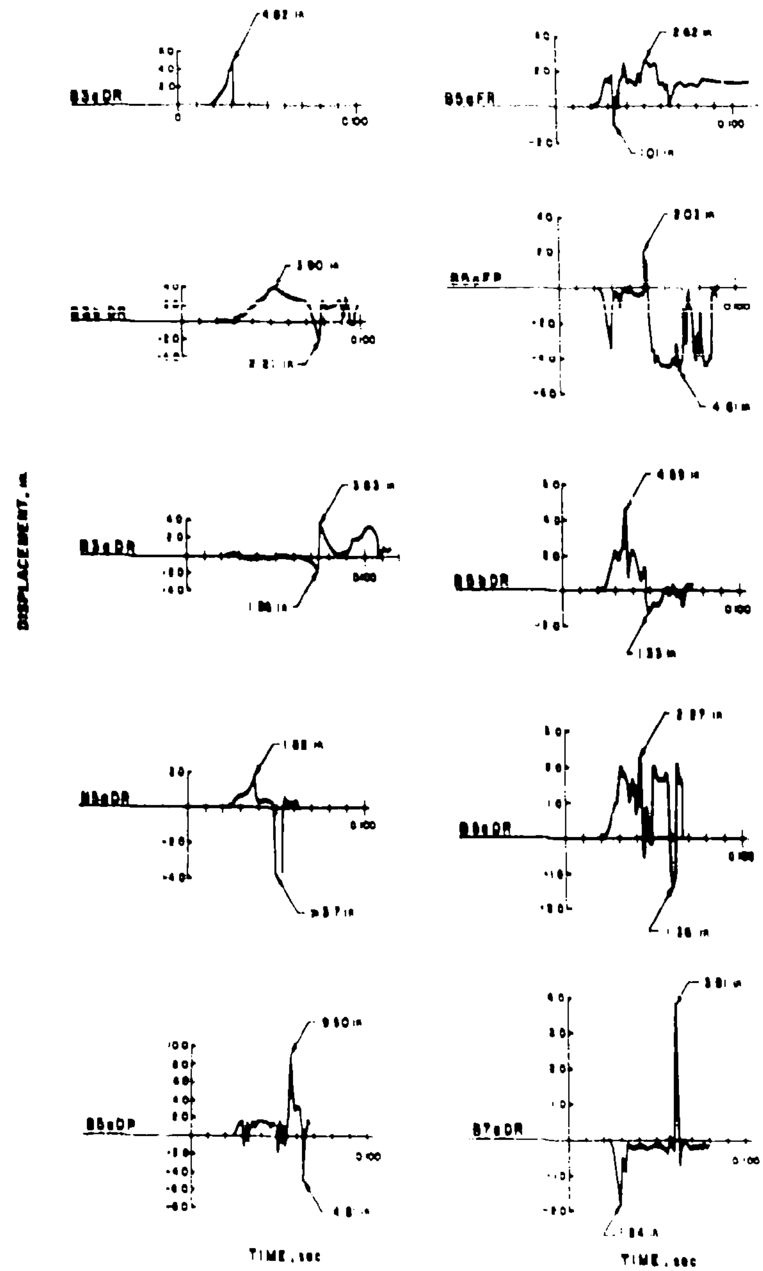


Figure 5.2 Measured relative displacements.



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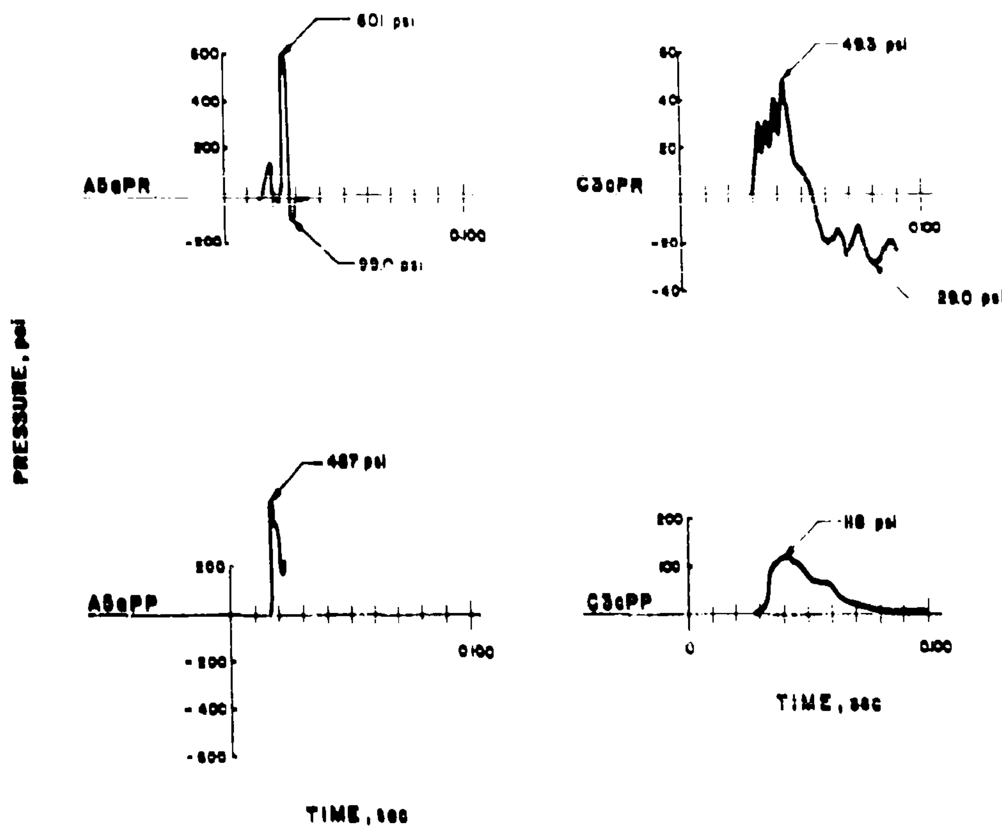
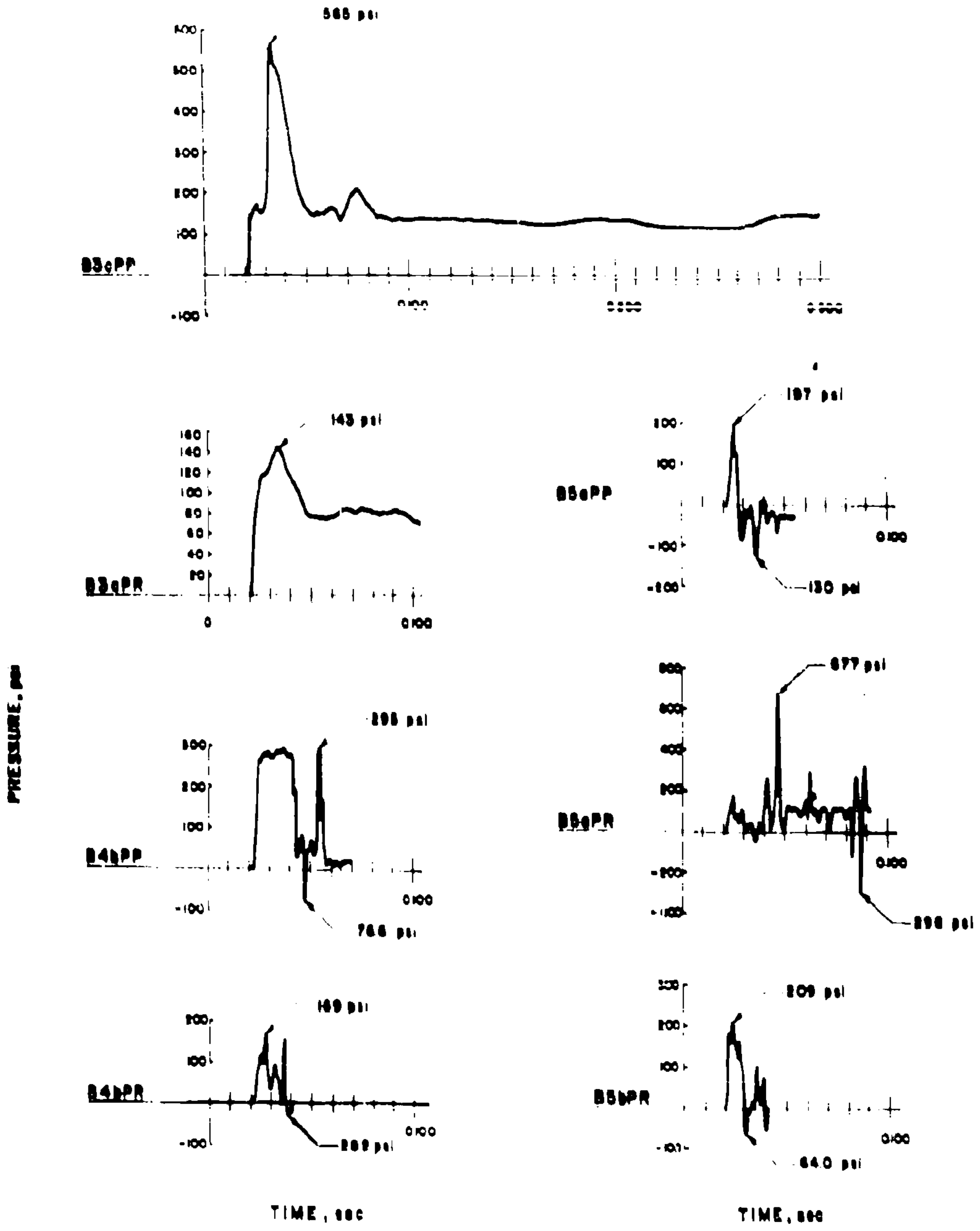


Figure 5.3 Pressure in foam.



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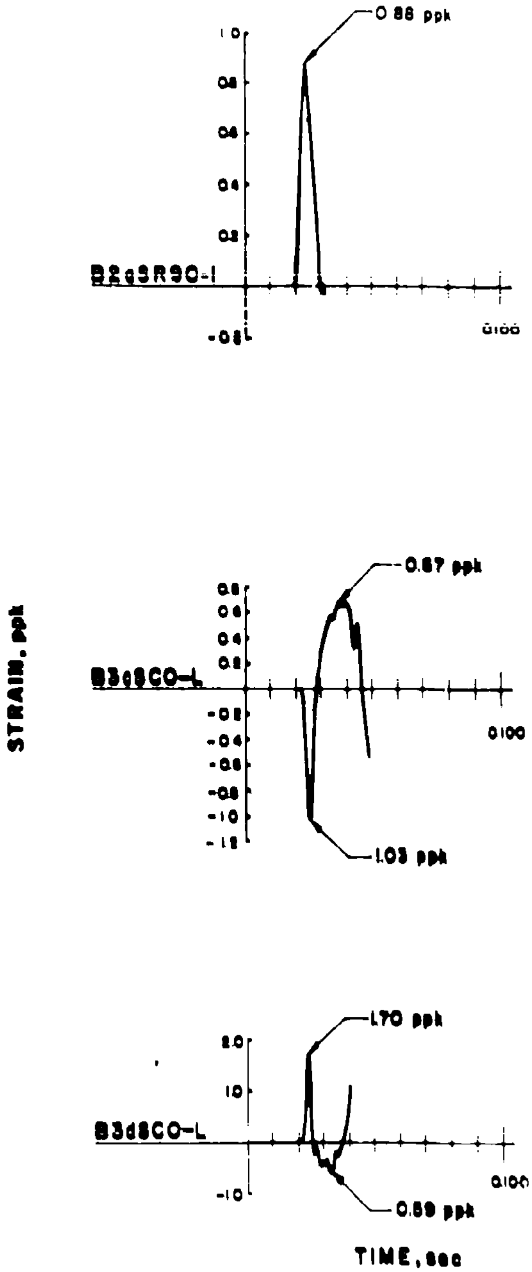

Figure 5.4 Strain in liners.

CHAPTER 6

DISCUSSION

The objective of this project did not include the analysis of the data obtained as it pertains to the loading and response of the liners. These responsibilities were taken by Project 3.1 which included the design and analysis of the entire experiment. The discussions in this report therefore are limited to pointing out features of the data obtained that are considered pertinent to and of interest to other projects and which assist in the evaluation of the data obtained.

6.1 COMPARISON WITH PREDICTIONS

The overall experiment was designed with experimental liners at each of three ranges. One of the purposes of such a division was to insure that at least one of the three sets of liners would be loaded to the point of at least partial failure so as to provide useful data. Ideally, it was expected that the liners in A drift would be severely damaged, those in B drift appreciably damaged, and those in C drift essentially undamaged.

The study of the gage records only does not show conclusively the extent of the damage suffered by the liners, but postshot inspection and exploration show that, indeed, the damage did follow this most desirable pattern.

It was pointed out in Section 3.4 that the set ranges on this project were based on, but were in general lower than, predictions of the free-field phenomena made by both projects. In Table 5.1 the ratio of the observed peak values to their predicted peaks, in terms of percent of set range, are shown in the last column. These data are summarized in Table 6.1, where it is obvious that predictions of velocity and pressure were slightly low, while predictions of relative displacement were somewhat high as judged by the geometric mean of the measurements obtained. The scatter from these mean values is relatively great, especially in the relative displacement measurements, but this is to be expected in

a project of this type. The sharp spikes observed on the records and mentioned in Section 5.2 are responsible for much of this scatter.

6.2 DIRECTION OF LOADING AND RESPONSE

Casual inspection of the data of Table 5.1 may result in conclusions which are not warranted. In three liners, measurements were made of relative displacements in the transverse (nearly vertical) direction (PP) as well as the radial direction (PR). In all three- A5a, A5b, and B5a- the transverse deflections DP were larger than the radial deflections DR by a considerable margin.

Where foam stress was measured in the transverse as well as the radial direction, three of the five liners- B3c, B4b, and C3c- showed the greatest stress in the transverse position; the other two- A5a and B5a- showed a maximum in the radial position.

From these observations, it appears that the majority of the structures showed maximum loading in a direction nearer the transverse than the radial direction. In fact, posttest examination of some of the structures show indications that this is true of the final positions.

But this conclusion is unwarranted from the data quoted above alone. The conventions of polarity used are such that the positive DR should be compared with the negative DP, since they represent inward motion. The rather high negative peaks of A5aDP and B5aDP are both quite sharp spikes and are unimportant if not spurious. The statistical approach to the foam stress results is not warranted, five being too small a number for such an approach.

The relative magnitudes of B5aFR and B5aFP are also of interest in this respect. In Figure 5.2, B5aFR is seen to be predominantly positive, whereas B5aFP is predominantly negative, indicative of an increased spacing between the liner and the formation (thickness of foam) in the transverse position accompanied by a decrease of this dimension in the radial position. The relative displacement gages B5aDR and DP show that the diameter of the liner is decreased radially and increased transversly, so that it appears that both the liner and the tunnel are distorted in the same direction, the tunnel more than the liner. The early foam stress is positive in both positions, but B5aPP drops to zero before B5aFP reaches its peak, as might be expected. This structure, then, responded as expected, except for the unexpected increase in "foam thickness" at 90°.

6.3 SHOCK VELOCITY

Figure 6.1 shows comparison of the arrival times observed on this project with those observed in the free-field measurements of Project 3.3 as quoted in Reference 6. The free-field measurements show propagation velocity in the ranges of interest from about 17,600 ft/sec All of the definite arrival times shown on Table 5.1 are later than those shown on this curve by times ranging from 0.5 millisecond to 3.5 milliseconds. This is to be expected, since there should be a considerable delay of the shockwave passing through the foam backing of the liners. The general trend confirms the velocity determined from Project 3.3 data.

TABLE 6.1 COMPARISON OF MEASUREMENTS WITH SET RANGES

Type of Measurements	Number of Measurements	Percent of Set Range Max.	Min.	Geometric Mean	Max/Mean	Mean/Min
VR	13	370	37	123	3.0	3.33
VR-180	3	227	37	116	1.96	3.1
V (total)	15	370	37	132	2.8	3.6
DR	13	121	8.7	51	2.35	5.9
DP	3	237	43	99	2.4	2.5
D (total)	16	237	8.7	57	4.2	6.5
PR	6	451	41	132	3.4	3.2
PP	5	376	98		1.6	1.7
P (total)	11	451	41	146	3.1	3.6
FR	1			87		
FP	1			153		
F (total)	2	153	87	1.14	1.34	1.34
SR-90-1	1			32		
SCO-L	2	85	52	66	1.28	1.28
S (total)	3	85	32	52	1.63	1.63
All	48			94		

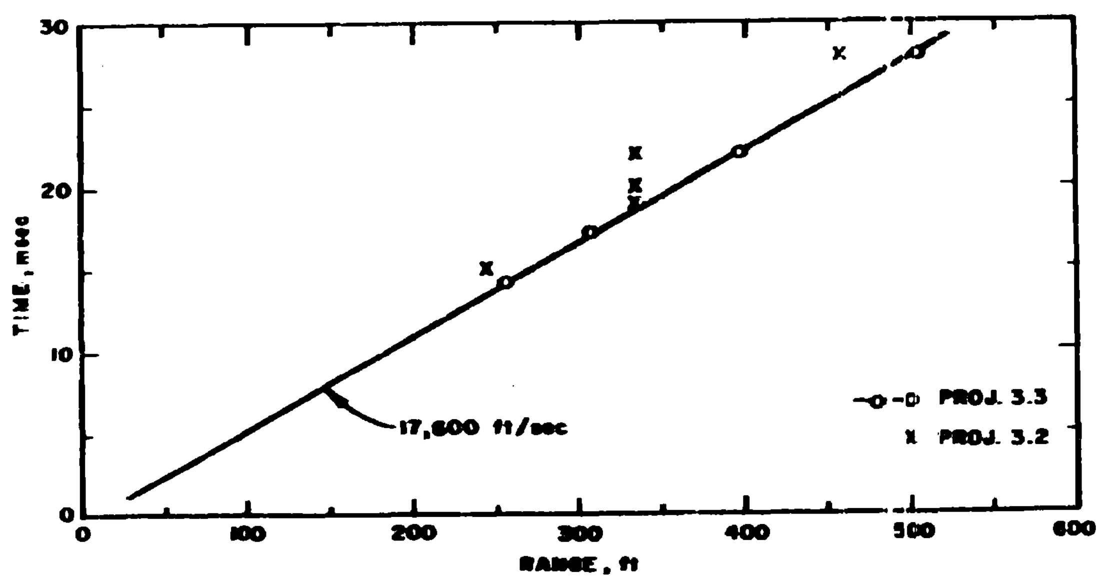

Figure 6.1 Arrival times, Projects 3.2 and 3.3.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The technical conclusion to be drawn from the results of this project is that the present state of knowledge permits extrapolation of data from one medium to another with sufficient accuracy for range setting and perhaps for tentative structural design. This position should be further improved after the final interpretations of the overall experiment.

The primary recommendation derived from this experiment is that, if there is a future similar experiment, much more drastic means should be used to protect the cable from damage by flying and shifting rock and to protect the gage system from the induction signal at zero time. Work is progressing along the latter direction in the course of planning of other underground experiments.

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[illegible] OF TRANSPORTATION DA
7- 8 U S ARMY COMBAT DEVELOPMENTS COMMAND
9 DIRECTOR OF SPECIAL WEAPONS DEVELOPMENT OFFICE
10 U S ARMY ARTILLERY BOARD
11 U S ARMY AIR DEFENSE BOARD
12 U S ARMY COMMAND AND GENERAL STAFF COLLEGE
13 U S ARMY AIR DEFENSE SCHOOL
14 U S ARMY ARMORED SCHOOL
15 U S ARMY ARTILLERY & MISSILE SCHOOL
16 U S ARMY AVIATION SCHOOL
17 U S ARMY INFANTRY SCHOOL
18 U S ARMY ORDNANCE & GUIDED MISSILE SCHOOL
19 CHEMICAL CORPS TRAINING COMD
20 ENGINEER SCHOOL
21 ARMED FORCES INSTITUTE OF PATH
22 ARMY MEDICAL RESEARCH LAB
23 WALTER REED ARMY INST OF RES
24 ENGINEER RESEARCH & DEV LAB
25 WATERWAYS EXPERIMENT STATION
26 PICATINNY ARSENAL
27 DIAMOND ORDNANCE FUZE LABORATORY
28- 29 BALLISTIC RESEARCH LABORATORY
30 WHITE SANDS MISSILE RANGE
31 U S ARMY MUNITIONS COMMAND
32 U S ARMY ELECTRONIC PROVING GROUND
33 U S ARMY COMBAT SURVEILLANCE AGENCY
34 THE RESEARCH & ANALYSIS CORP

NAVY ACTIVITIES

35- 36 CHIEF OF NAVAL OPERATIONS OP03EG
37 CHIEF OF NAVAL OPERATIONS OP-75
38- 39 CHIEF OF NAVAL RESEARCH
40- 42 BUREAU OF NAVAL WEAPONS DLI-3
43 BUREAU OF SHIPS CODE 423
44 BUREAU OF YARDS & DOCKS
45 U S NAVAL RESEARCH LABORATORY
46- 47 U S NAVAL ORDNANCE LABORATORY
48 NAVY ELECTRONICS LABORATORY
49 U S NAVAL MINE DEFENSE LAB
50- 51 U S NAVAL RADIOLOGICAL DEFENSE LAB
52- 53 U S NAVAL CIVIL ENGINEERING LAB
54 U S NAVAL SCHOOLS COMMAND TREASURE ISLAND
55 U S NAVAL POSTGRADUATE SCHOOL
56 U S NAVAL SCHOOL PORT HUENEME
57 NUCLEAR WEAPONS TRAINING CENTER ATLANTIC
58 NUCLEAR WEAPONS TRAINING CENTER PACIFIC
59 U S NAVAL DAMAGE CONTROL TNG CENTER
60 NAVAL AIR MATERIAL CENTER
61 U S NAVAL AIR DEVELOPMENT CENTER
62 US NAVAL AIR SP WPNS FACILITY
63 U S NAVAL MEDICAL RESEARCH INSTITUTE
64 DAVID W TAYLOR MODEL BASIN
65 U S NAVAL ENGINEERING EXPERIMENT STATION
66 U S NAVAL SUPPLY R&D FACILITY
67 NORFOLK NAVAL SHIPYARD
68- 71 U S MARINE CORPS CODE A03H

AIR FORCE ACTIVITIES

72 HQ USAF AFTAC-TD
73 HQ USAF AFRDC-AE
74 HQ USAF AFRDR-NU
75 HQ USAF AFOCE
76 HQ USAF OPERATIONS ANALYSIS OFFICE
77- 81 HQ USAF AFCIN-3D1
82 AC OF S INTELLIGENCE
83 DC OF S RESEARCH & TECHNOLOGY
84 THE SURGEON GENERAL
85 TACTICAL AIR COMMAND
86 AIR DEFENSE COMMAND
87 AIR FORCE SYSTEMS COMMAND
88 AIR FORCE BALLISTIC SYSTEMS DIVISION
89 RADC-RAALD,GRIFFISS AFB
90 PACIFIC AIR FORCES
91 SECOND AIR FORCE
92- 93 AF CAMBRIDGE RESEARCH CENTER
94- 98 AFSWC KIRTLAND AFB NMEX
99-100 AIR UNIVERSITY LIBRARY
101 LOWRY AFB
102 SCHOOL OF AVIATION MEDICINE
103-105 AERONAUTICAL SYSTEMS DIVISION
106-107 USAF PROJECT RAND
108 AIR TECHNICAL INTELLIGENCE CENTER
109 OFFICE OF AEROSPACE RESEARCH
110 HQ USAF AFORO

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

111 DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
112 ASST TO THE SECRETARY OF DEFENSE ATOMIC ENERGY
113 ADVANCE RESEARCH PROJECT AGENCY
114 WEAPONS SYSTEM EVALUATION GROUP
115 ASST SECRETARY OF DEFENSE INSTALLATION & LOGISTICS
116-119 DEFENSE ATOMIC SUPPORT AGENCY
120 FIELD COMMAND DASA
121 FIELD COMMAND DASA FCTG
122-123 FIELD COMMAND DASA FCWT
124 NATIONAL AERONAUTICS & SPACE ADMINISTRATION
125-126 DEFENSE INTELLIGENCE AGENCY
127 ARMED SERVICES EXPLOSIVES SAFETY BOARD
128 JOINT TASK FORCE-8
129 COMMANDER-IN-CHIEF EUCOM
130 COMMANDER-IN-CHIEF PACIFIC
131 COMMANDER-IN-CHIEF ATLANTIC FLEET
132 STRATEGIC AIR COMMAND
133 CINCONAD
134-136 ASST SECRETARY OF DEFENSE CIVIL DEFENSE

FOR CIVILIAN DISTR CAT. A 2

137 UNITED ELECTRODYNAMICS INC PASADENA
138 SPACE TECH LAB LOS ANGELES ATTN SUSSHOLZ
139 MIT CAMBRIDGE MASS ATTN HANSEN
140 US COAST &GEODETIC SURVEY WASHINGTON ATTN MURPHY
141 STANFORD RESEARCH INST MENLO PARK ATTN VAILE
142 SANDIA CORP SANDIA BASE ALBUQUERQUE ATTN CLASS DOC
143 US GEO SURVEY DENVER COL ATTN ROACH
144 US GEO SURVEY DENVER COL ATTN PAKISER
145 HOLMES AND NARVER FOUNDATION LOS ANGELES
146 ARMOUR RESEARCH FOUNDATION CHICAGO
147 GEOPHYSICS CORP OF AMERICA BEDFORD MASS
148 GEOTECHNICAL CORP GARLAND TEXAS
149 GEN AMERICAN TRANS CORP NILES ILL
150 DEPT OF CIVIL ENGR UNIV OF ILL URBANA ILL ATTN NEWM
151 UNITED SERVICES BURLINGAME CALIF

ATOMIC ENERGY COMMISSION ACTIVITIES

152-154 AEC WASHINGTON TECH LIBRARY
155-156 LOS ALAMOS SCIENTIFIC LAB
157-161 SANDIA CORPORATION
162-171 LAWRENCE RADIATION LAB LIVERMORE
172-175 NEVADA OPERATIONS OFFICE,LAS VEGAS
176 DTIE OAK RIDGE,MASTER
177-206 DTIE OAK RIDGE SURPLUS